Sediment Quality in Bellingham Bay, 2010

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Findings

- Chemical exposure was limited to inner Bellingham Bay
- Toxicity was found throughout the bay
- *Adversely affected* benthos were found at all sites
- No *unimpacted* sediments were found
- Mixed conditions occurred in the center of the bay, with more *impacted* conditions to the east and south
- Overall sediment quality did not meet the Puget Sound Partnership Triad Index target
- Sediment quality in Bellingham Bay was lower than in the encompassing region and Puget Sound

Want more information?

This report covers only the primary results of the 2010 survey. Data and supporting information are available on Ecology's website: www.ecy.wa.gov/programs/eap/sediment.

In 2010, the Washington State Department of Ecology (Ecology) conducted an intensive survey of Bellingham Bay (box in map at right) to establish a bay-wide baseline of sediment quality. Surface sediments (top 2-3 cm) from 30 randomly selected locations were analyzed to determine:

- Concentrations of potentially toxic chemicals.
- Degree of response in laboratory tests of toxicity.
- Condition of sediment-dwelling invertebrates (benthos).

The sediment contaminant, toxicity, and benthic invertebrate data were rolled up into Ecology's Chemistry, Toxicity, Benthic, and combined Triad Indices.

Overall Results

All four sediment quality indices for Bellingham Bay were significantly lower than those for the Strait of Georgia region in which the bay is located (pink in map above), indicating lower sediment quality for the bay in 2010 than for the region as a whole in 2006 (Figure 1).
Overall sediment quality, as measured by the Triad Index, did not meet the Puget Sound Partnership (PSP) target.
The Benthic Index was the primary contributor, with all benthos *adversely affected*.

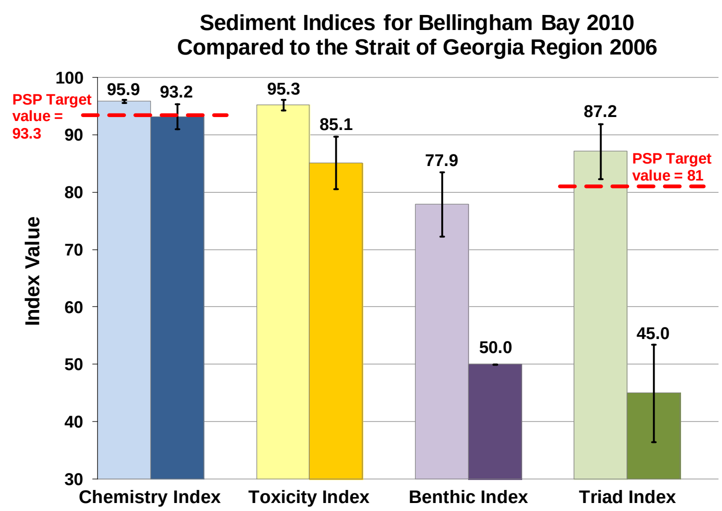

Figure 1. A comparison of weighted mean index values for Bellingham Bay in 2010 (darker bars) and the Strait of Georgia region in 2006 (lighter bars), with 95% confidence intervals. Also shown are the PSP target values for the Chemistry and Triad Indices (red dashed lines).

Sediment Monitoring of Bellingham Bay

Ecology surveyed Bellingham Bay surface sediments under the Puget Sound Ecosystem Monitoring Program (PSEMP). Bellingham Bay is part of the Strait of Georgia region, which had been studied previously in a survey conducted jointly by Ecology and the National Oceanic and Atmospheric Administration in 1997 (Long et al., 2005) and again in 2006 by Ecology (Partridge et al., 2012a, b) with the same field and laboratory methods. The survey design weights sample results by area, which enables Ecology to estimate the percent of area (spatial extent) with given sediment conditions and to compare results from multiple surveys at a glance. The study design, sampling and analytical methods, and list of parameters are described in Dutch et al. (2009, 2010) and on Ecology's website.

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Physical Conditions in Bellingham Bay

Sampling stations ranged from 3 to 31 meters deep. Sediments throughout Bellingham Bay were primarily silt and clay (>80% silt-clay). Total organic carbon (TOC) content of most of the sediment samples was less than 1%, ranging up to 3.4% by weight. TOC content was highest in the harbor areas.

Chemistry Index

Samples were analyzed for concentrations of 263 potentially toxic chemicals, including metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pharmaceuticals and personal care products (PPCPs), pesticides, and other organic compounds. Metals and PAHs were almost always detected and measurable (98% of samples). The other target organic compounds were detected in only 6% of samples.

The only contaminant to exceed (not meet) the Washington State Sediment Quality Standards (SQS) (Ecology, 2013) in 2010 was bis(2-ethylhexyl)phthalate at one location, near Fairhaven (Figure 2).

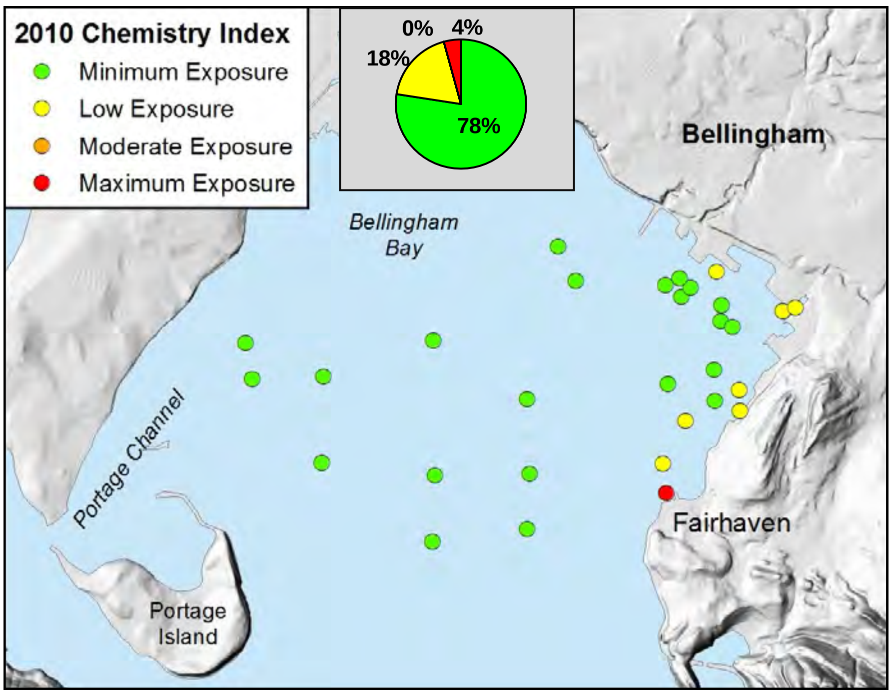

Figure 2. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Chemistry Index categories for Bellingham Bay in 2010.

Of the 119 PPCPs, diphenhydramine (an antihistamine) was detected at 28 of the 30 stations, triamterene (a diuretic) at 12 stations, and triclocarban (an antibacterial agent in hand soaps) at 9 stations. Only 10 other PPCPs were detected, at only 1-5 stations each. Further details on the PPCPs are given in Dutch et al. (2011) and Long et al. (2013a).

The Chemistry Index (Long et al., 2013b) indicated that 78% of the study area fell into the best category of *minimum exposure* to chemical contaminants (Figure 2). Ecology's Chemistry Index is an effects-based, multi-chemical index that accounts for the presence, concentrations, and potential toxicity of mixtures of chemicals. It is used to categorize sediments as having *minimum*, *low*, *moderate*, or *maximum* levels of exposure to the chemicals for which SQS have been defined.

Toxicity Index

In the 2010 survey, each sediment sample was analyzed with two laboratory toxicity tests: amphipod survival and sea urchin egg fertilization. The test results were combined into Ecology's Toxicity Index (Dutch et al., 2012) and characterized into four toxicity ranges, from *non-toxic* to *high toxicity* (Table 1).

Table 1. Toxicity Index category descriptions.

Category	Description
Non-Toxic	Mean control-adjusted test results were not significantly lower than the controls **or** were ≥90% of controls
Low Toxicity	Mean control-adjusted test results were significantly lower than the controls **and** between <90-80% of controls
Moderate Toxicity	Mean control-adjusted test results were significantly lower than the controls **and** between <80-50% of controls
High Toxicity	Mean control-adjusted test results were significantly lower than the controls **and** <50% of controls

The Toxicity Index indicated that the majority (63%) of the study area sediments had some degree of toxicity. *Low* and *moderate* toxicity was found throughout Bellingham Bay and represented 59% of the study area (Figure 3). Sediments with *high toxicity* were found at one site in the southeast area of the bay, west of Fairhaven. *Non-toxic* sediments were found in 37% of the study area.

Low toxicity sediments tended to occur in the center of the bay, surrounded by *non-toxic* sediments, with *moderate-high toxicity* sediments at the eastern and southern sides of the bay (Figure 3).

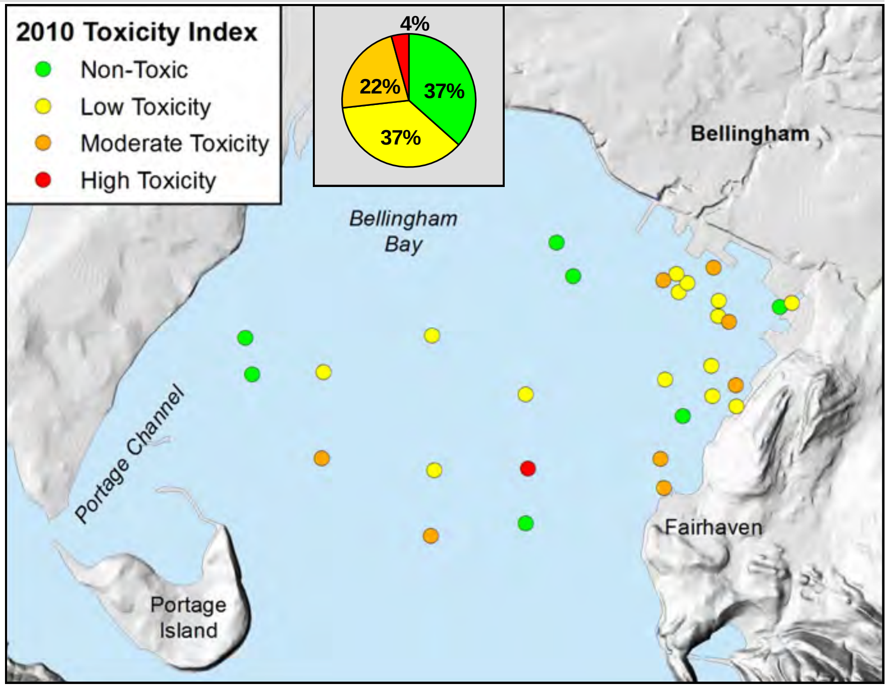

Figure 3. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Toxicity Index categories for Bellingham Bay in 2010.

Benthic Index

Benthic invertebrate organisms (benthos) were identified and counted for all 30 locations sampled in 2010, and multiple benthic measures were calculated. Total abundance and taxa richness (number of species) tended to be higher in the eastern portion of the bay, closest to the city of Bellingham. Annelids (marine worms) were numerically dominant in every site and throughout Bellingham Bay. The stress-tolerant *Aphelochaeta* annelids were among the dominant species at all but one sampling site. Arthropods, molluscs, echinoderms, and miscellaneous taxa were sparsely represented.

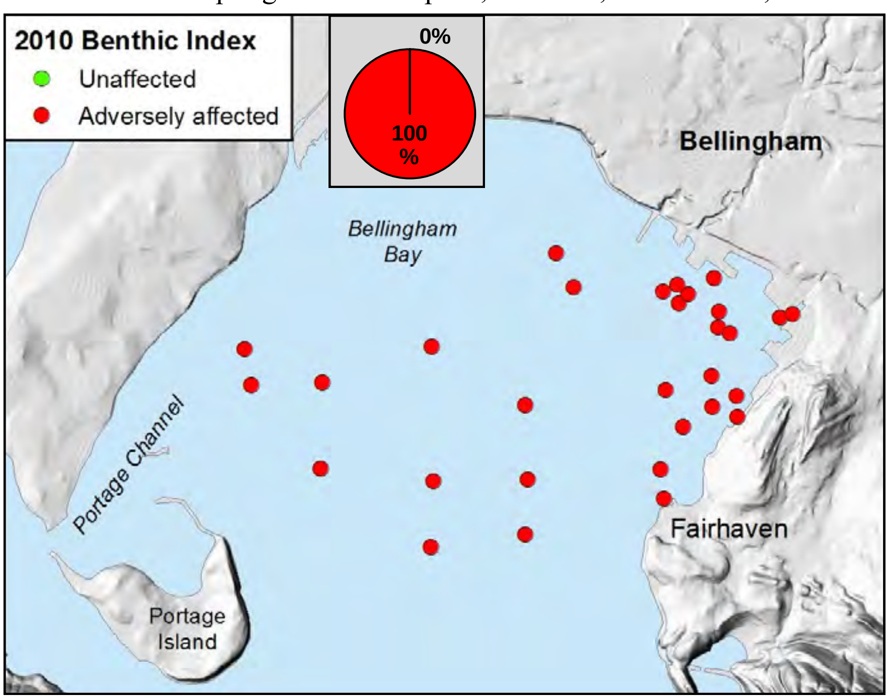

Figure 4. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Benthic Index categories in Bellingham Bay in 2010. All sites had *adversely affected* benthic invertebrate communities.

The benthos were judged to be *adversely affected* in all samples, according to Ecology's Benthic Index (Figure 4). These findings are of concern and indicate that Bellingham Bay sediment quality is not adequate to support a diverse population of benthic organisms.

The Benthic Index is a determination of whether the invertebrate assemblages appear to be *adversely affected* or *unaffected* by natural and/or human-caused stressors. The determination is made by benthic experts, based on assessment of a suite of calculated indices, including total abundance, major taxa abundances, taxa richness, evenness, and species dominance, compared to median values for all of Puget Sound. Abundances of stress-sensitive and stress-tolerant species at each station are also considered.

Benthic communities have not always been *adversely affected* in Bellingham Bay. Benthic invertebrate samples collected there as part of larger regional surveys (Long et al., 2005; Partridge et al., 2012a, b) suggest that conditions changed between 1997 and 2006 (Figure 5). The 2010 samples were taken at the same locations as the 1997 and 2006 samples combined (plus one more). Although the numbers of samples in the earlier years are not sufficient to draw definite conclusions, the results are certainly suggestive of changes taking place after 1997.

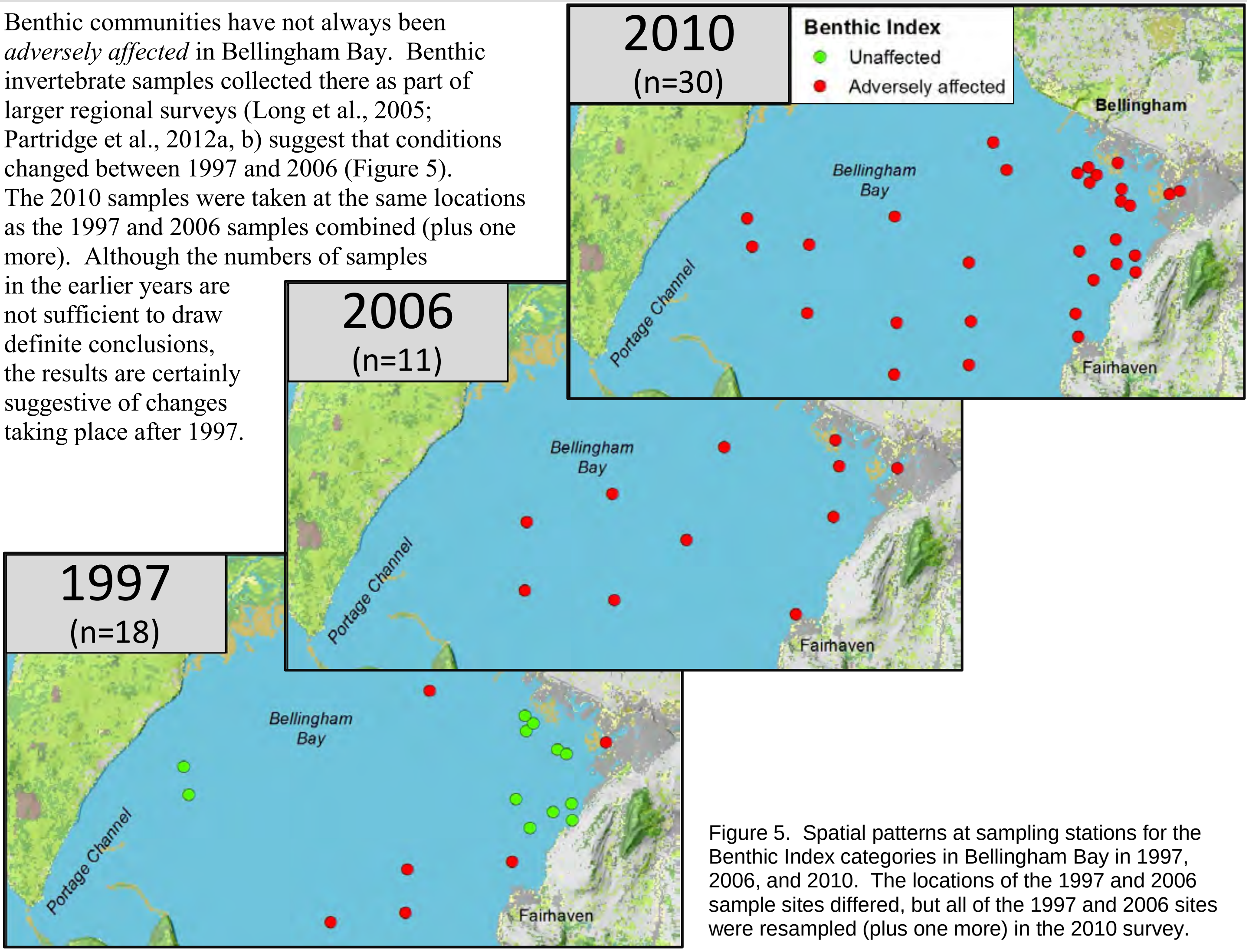

Figure 5. Spatial patterns at sampling stations for the Benthic Index categories in Bellingham Bay in 1997, 2006, and 2010. The locations of the 1997 and 2006 sample sites differed, but all of the 1997 and 2006 sites were resampled (plus one more) in the 2010 survey.

Triad Index

Ecology's Triad Index combines evidence from the triad of measures (chemistry, toxicity, benthos) to classify sediment quality into six categories of impact by chemical contamination and/or other environmental stressors (Dutch et al., 2012). Categories range from *unimpacted* to *clearly impacted*, and *inconclusive* when lines of evidence are conflicting. This multiple-lines-of-evidence approach was adapted from methods developed for the state of California to classify sediment quality (Bay and Weisberg, 2012).

Table 2. Specific combinations of index results (chemistry, toxicity, benthic) that led to Triad Index categories for Bellingham Bay in 2010. Spatial extent (percent of study area) is given for each combination.

<table>
<tr><th>Chemistry Index</th><th>Toxicity Index</th><th>Benthic Index</th><th>Triad Index</th><th>% of Area</th></tr>
<tr><td colspan="2">Combinations of no to low toxicity and minimum to low exposure</td><td>Unaffected</td><td>Unimpacted</td><td>0.0</td></tr>
<tr><td>Minimum exposure</td><td rowspan="2">Non-Toxic</td><td rowspan="9">Adversely affected</td><td rowspan="2">Likely unimpacted</td><td>31.9</td></tr>
<tr><td rowspan="2">Low exposure</td><td>4.7</td></tr>
<tr><td>Low toxicity</td><td rowspan="2">Possibly impacted</td><td>4.7</td></tr>
<tr><td>Minimum exposure</td><td rowspan="2">Moderate</td><td>9.4</td></tr>
<tr><td>Low exposure</td><td rowspan="2">Likely impacted</td><td>8.9</td></tr>
<tr><td>Minimum exposure</td><td>High toxicity</td><td>4.2</td></tr>
<tr><td>Maximum exposure</td><td>Moderate</td><td>Clearly impacted</td><td>4.2</td></tr>
<tr><td>Minimum exposure</td><td>Low toxicity</td><td>Inconclusive</td><td>31.9</td></tr>
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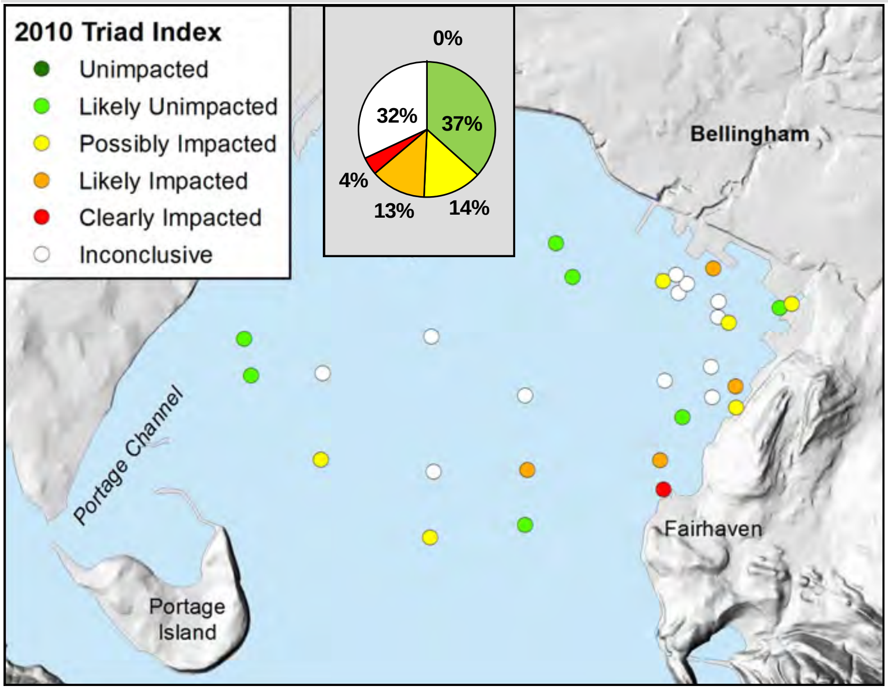

Figure 6. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Triad Index results in Bellingham Bay in 2010. No *unimpacted* sediments were found.

In 2010, none of the study area was classified as *unimpacted* (Table 2; Figure 6). *Likely unimpacted* sediments represented 37% of the area. Sediments which were *possibly impacted* and *likely impacted* by chemical contamination and/or other environmental stressors were found in about 27% of the study area. Sediments were *clearly impacted* at one site representing 4% of the area. The remaining 32% of the area was classified as *inconclusive*, with conflicting Chemistry, Toxicity, and Benthic Index results.

The *inconclusive* conditions appear to occur in the center of the bay, with various degrees of *impacted* sediment quality at the margins, especially to the east and south (Figure 6). *Inconclusive* conditions coincided with *low toxicity* (Figure 3) and *minimum exposure* to contaminants, as well as *adversely affected* benthos (Table 2).

Bellingham Bay Compared to the Strait of Georgia and All of Puget Sound

Comparison of the 2010 Bellingham Bay Triad Index results to those for the 2006 Strait of Georgia regional survey and the 1997-2003 Puget Sound baseline shows that Bellingham Bay had significantly lower sediment quality than both (Figure 7). The *adversely affected* condition of the benthos and *low toxicity* were the primary factors influencing the extents of the Triad Index categories for Bellingham Bay.

Sediment quality for the entire Strait of Georgia region in 2006 also was significantly lower than sediment quality for all of Puget Sound in 1997-2003 (Figure 7). Partridge et al. (2012a, b) reported a decrease in high-quality sediments and a corresponding increase in intermediate-quality sediments in the Strait of Georgia region in 2006 compared to 1997. Deterioration in benthic health was the driving factor in that change.

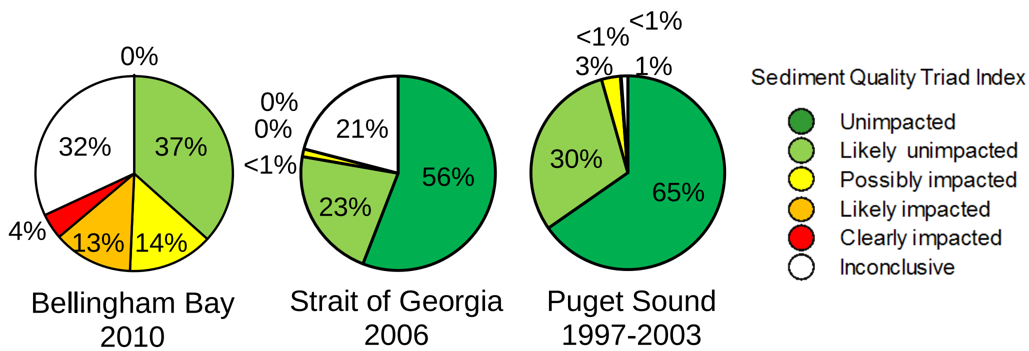

Figure 7. Spatial extent (percent of area) for the Triad Index categories for Bellingham Bay in 2010 (from Figure 6), compared to the Strait of Georgia region in 2006 and the whole-Puget-Sound baseline for 1997-2003.

The Chemistry Index and the Triad Index as "Vital Signs" Indicators for the Puget Sound Partnership

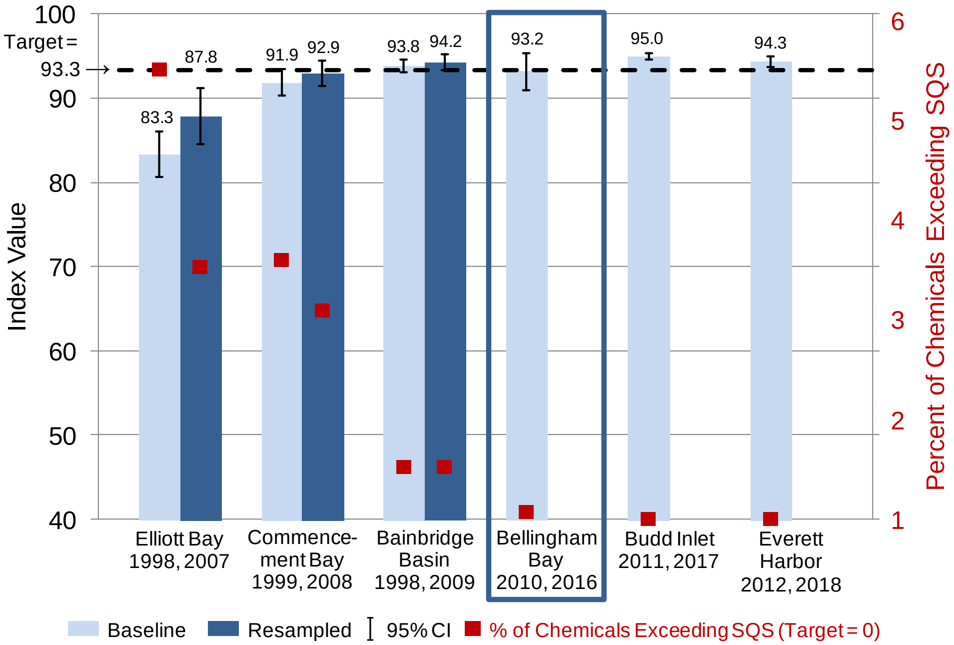

Figure 8. Change over time in Chemistry Index values for six urban bays in Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. The PSP's 2020 target value of 93.3 is shown as a dashed black line. Red squares illustrate the percentages of chemicals with concentrations exceeding SQS.

Ecology's Chemistry and Triad Indices, and also the percent of chemicals exceeding Washington Sediment Quality Standards (SQS) (Ecology, 2013), were adopted by the Puget Sound Partnership (PSP) to serve as "Vital Signs" indicators of the condition of Puget Sound (www.psp.wa.gov/vitalsigns/index.php).

Weighted mean Chemistry and Triad Index values are compared with target values for highest quality for 2020, adopted by the PSP. The indices also are compared between years of repeated sampling to determine changes over time, as well as among urban bays.

The Chemistry Index value for Bellingham Bay was just below the target value of 93.3 but statistically met the target because the 95% confidence interval covers the target (Figure 8). The percent of chemicals exceeding SQS in Bellingham Bay did not meet the target of zero.

The Triad Index value for the 2010 Bellingham Bay survey was below the PSP's target value of 81 (Figure 9). The Bellingham Bay Triad Index value also was significantly lower than the Triad Index value for any of the other urban bays except Budd Inlet.

The contribution of the Benthic Index (the condition of the benthic invertebrate assemblages) throughout Bellingham Bay was the primary driving factor, with the Toxicity Index results the secondary driver.

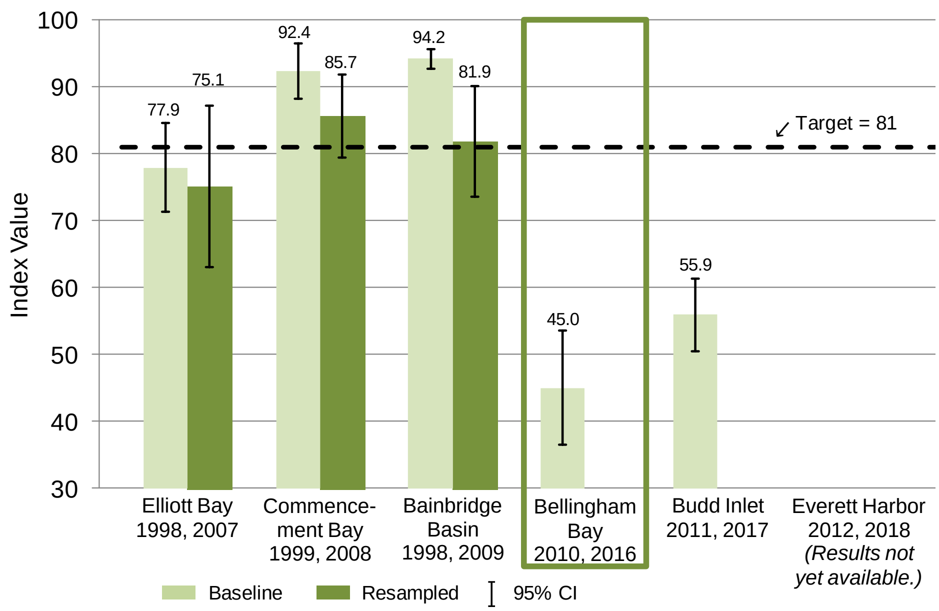

Figure 9. Change over time in Triad Index values for six urban bays in Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. Also shown is the PSP's 2020 target value of 81 (dashed black line).

Summary and Conclusions

Benthic invertebrate communities were *adversely affected* at all stations sampled in the 2010 survey of Bellingham Bay. We found a low abundance and diversity of organisms and a prevalence of the stress-tolerant polychaete annelid *Aphelochaeta* spp.

Sediment quality throughout Bellingham Bay was mixed, as indicated by the Triad Index. About one-third (37%) of the area was classified as *likely unimpacted*; about one-third (31%) was classified as *possibly*, *likely*, or *clearly impacted*; and about one-third (32%) was classified as *inconclusive*. The varying degrees of toxicity were the secondary contributor to the overall sediment quality results, after the *adversely affected* benthos.

Results followed a geographical pattern, with the greatest degrees of toxicity and *impacted* conditions occurring along the east and northeast margins of the bay and to the south by the open mouth. *Low toxicity* and *inconclusive* conditions characterized the center of the bay because of the conflicting conditions of *minimum exposure* to contaminants, *low toxicity*, and *adversely affected* benthos.

None of the physical or chemical parameters measured in this 2010 survey explained the observed patterns of sediment quality conditions. Further study would be required to identify other factors, such as dissolved oxygen or additional contaminants, that may be important.

Future Directions and Recommendations

Some enhancements to Ecology's marine sediment monitoring program are already planned, while others will require additional resources:

- Increase coordination, data-sharing, and collaboration with other monitoring and research efforts.
- Examine additional environmental variables which may be affecting the benthos, such as (1) water quality measures, including near-bottom dissolved oxygen, pH, and nutrient levels, (2) rates of sediment deposition, mixing, and resuspension, and (3) patterns of sediment transport.
- Improve Puget Sound chemistry, toxicity, and benthic indicators by (1) quantifying new suites of chemicals of concern, (2) adopting better methods of toxicity testing, including toxicity tests which are responsive to chemicals of emerging concern, and (3) applying a multivariate benthic index for Puget Sound (in development).

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